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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01J 3/00, 3/46 — A1

(11) International Publication Number: WO 98/12520

(43) International Publication Date: 26 March 1998 (26.03.98)

(21) International Application Number: PCT/IB97/01224

(22) International Filing Date: 5 September 1997 (05.09.97)

(30) Priority Data:
08/708,739 5 September 1996 (05.09.96) US

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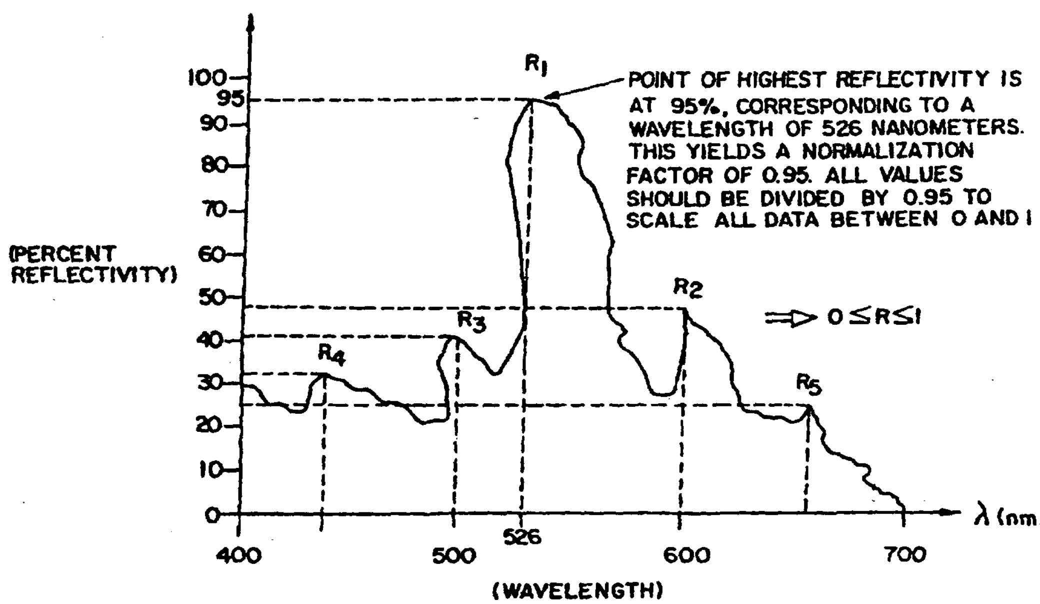
(81) Designated States: AU, JP, SG, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: SPECTROPHOTOMETRIC NEURAL NETWORK



(57) Abstract

A spectrophotometric neural network assists in the color matching process for pigments. The self-teaching system provides an accurate means of automating the determination of pigment recipes for color matching. The neural network uses the reflectivity values (R1-R5) obtained through a spectrophotometric scan as input to the process. Full automation of such a system employs the interface of a neural network, a computer, a spectrophotometer, and pigment-mixing equipment.

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SPECTROPHOTOMETRIC NEURAL NETWORK

Field Of The Invention

This invention relates to methods to detect discrepancies in the color matching process. In particular it relates to quality control of the color printing on compact discs. Further it relates to the use of neural network in the color matching process.

Background Of The Invention

Compact discs are data media having a metal layer formed by metal deposition over a transparent plastic substrate having pits of varying length. The data is encoded by the dimensions of the pits and can be read by a laser that passes through the transparent surface of the disc to reach the metal layer. On the reverse side of the metal layer additional material is deposited to build up the thickness of the disc. This reverse side need not be transparent and typically a label is printed there. The label often contains attractive art work having many colors and quality control procedures are necessary to ensure uniformity of the final product during mass production processes and to be sure that the final colors formed by color mixing are what was intended.

To maintain uniformity in the final product

some method for color matching is necessary. Color matching has required a great deal of trial and error techniques, where formulas for new colors were generated by mixing random proportions of constituent colors until a suitable new color was developed. Verification of the new color came about using a manual eyesight color matching test.

The use of a manual eyesight color matching test adds a great deal of error to color matching. The varied color sensitivity in the eyesight of the various individuals involved in a series of color matching tests alone presents variation in color matching trials. A trial-to-trial comparison of the resultant colors will reveal these differences simply by human eyesight.

Brief Description Of The Invention

The present invention concerns an automated system for performing color matching for designs on compact discs so that the paints are properly mixed to provide the desired color spectrum. The color sample is first analyzed on a spectrophotometer. Spectrophotometric reflectivity wavelength interval samples are recorded and sent to the inputs of a neural network. The customized structure of the neural network then yields error values which signify a variance from the correct color. A continuous feedback loop, which

includes the color mixing equipment, allows corrections to the color recipe to be made until the color has been correctly matched.

The Spectrophotometric Neural Network permits color matching in a manner that reduces the trial-to-trial differences of the resultant colors to a point of being negligible. The human element of color matching is mostly eliminated, as the employment of neural networks for this task relies upon the numerical analysis of a computer and the accurate spectral analysis of a spectrophotometer.

Brief Description Of The Drawings

Figure 1 is a graph of the reflectivity of a sample to be color matched as a function of wavelength.

Figure 2 is a schematic representation of the back propagation neural network used in connection with the present invention.

Detailed Description Of A Preferred Embodiment

As with any color matching procedure, some reference color must be chosen. The reference color is that color which is to be reproduced by combining some set proportion of primary pigments or secondary pigments. The primary pigments (red, yellow, blue) are apart from

the primary colors (red, green, blue).

Once the reference color is known, a spectrophotometric scan must be obtained. The resolution of the scan (wavelength increments) is directly proportional to the accuracy of the color match. While arbitrary, a preferred wavelength increment is 0.1 nanometers. The spectral range to be covered is that of the visible light spectrum from 400 nanometers to 700 nanometers. A neural network is employed to determine the accuracy of the color match. The usage of this neural network is not limited to only the visible spectrum (ultraviolet and infrared can also be analyzed).

The end result of the spectrophotometric scan is a reflectivity value for each wavelength increment running from the lower wavelength limit to the upper wavelength limit. Using 0.1 nanometer increments from 400 nanometers to 700 nanometers yields 3010 reflectivity values. These reflectivity values act as the inputs to the neural network.

A back-propagation neural network is preferred for this application due to its ability to readily adapt to the training process. The neural network is a collection of logical nodes arranged in layers with the nodes in one layer connected to the nodes in many nodes in other layers. Each node processes the input it

receives through these connections. The strengths of the connections changes in response to the strengths of the inputs and the transfer function used by the node. The transfer function mathematically expresses the relation between input and output. A neural network is defined by how its nodes are created, how the nodes process the information that they receive and how the connection strengths are modified.

The preferred neural network of the present invention is a back-propagation feed-forward network. In this network data flows only in one direction from layer to layer. This is contrasted with feedback and recurrent networks in which the nodes are connected such that a later layer may provide information back to an earlier layer. The network of the preferred embodiment is a trained network. The training of the network is a procedure consisting of providing the network with typical expected inputs at an input layer and the desired outputs at the output layer. The nodes are then adjusted so that repetitions of these inputs will produce the desired outputs. The network is then "trained" in a supervised learning procedure termed Hebbian learning to provide similar outputs for similar inputs. Initially the network produces erroneous answers and an error is calculated. The error is used to adjust the weights in

the network to approximate the correct response.

The training process takes place by collecting several sample colors, taking their respective spectrophotometric data, and presenting this data to the inputs of the back-propagation neural network. As shown in Fig. 1 the data is input to the neural network in the form of the amplitude of the percent reflectivity at local maxima of the amplitude normalized to the highest reflectivity within the wavelength range from 400 to 700 nm. In addition, the slope reversal average and the slope reversal difference are provided to nodes, so that seven input nodes are provided on the back propagation neural network. Where R1 through R5 represent values of relative highest reflectivity, the slope reversal average <R> is 1/5(Sum of R1 through R5). The slope reversal difference RD = R1 - R5. Figure 2 shows the three levels of the neural network. There is one hidden network of five nodes and three output which are assigned for training purposes to the three tristimulus vales for red, green and blue. The expected output for each color is revealed to the output nodes of the neural network, as well.

In an example of the method 3010 reflectivity values are supplied to 3010 input nodes, and 1 wavelength value to 1 output node (representing the wavelength of

the respective color). Training of the network occurs under the previously described provisions and requirements of the back-propagation neural network paradigm.

With training complete, testing occurs by presenting new reflectivity values to the input nodes of the neural network. An output value is generated by the neural network as a result of the presented input values. This output value is the wavelength of the color presented to the spectrophotometer for analysis. If a color was properly matched to a reference, its neural network output value should be quite close to that of the reference. Otherwise, its neural network output value will differ from that of the reference in a manner proportional to its actual variance from the reference.

The neural network can be automated by interfacing its computer with ink mixing equipment and a spectrophotometer in a fashion that allows the mixing equipment to adjust the pigment blend until the spectrophotometer-generated reflectivity values generate the correct output wavelength of the color desired through the neural network.

While there have been shown and described and pointed out the fundamental novel features of the invention as applied to preferred embodiments thereof, it

will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art without departing from the spirit of the invention, exemplified in the following claims.

I claim:

1. An automated system for performing color matching for designs on compact discs comprising

(a) analyzing a color sample on a spectrophotometer and determining a sequence of relative maxima of reflectivity as a function of wavelength,

(b) determining a slope reversal average and slope reversal difference for said sample,

(c) inputting said points of values of relative maxima, slope reversal average and slope reversal difference to the input layer of a back-propagation neural network,

(d) training said neural network to reproduce three values of tristimulus amplitudes for red, green and blue primary colors,

(e) employing an automated process comprising a continuous feedback loop, which includes the color mixing equipment, to allow corrections to the color recipe to be made until the color has been correctly matched.

2. An automated system for performing color matching for designs on compact discs comprising

(a) analyzing a color sample on a spectrophotometer and determining the reflectivity at predetermined wavelength intervals in a predetermined spectral range,

(b) determining an average reflectivity and reflectivity difference for said sample,

(c) inputting said values of reflectivity, average reflectivity and reflectivity difference to the input

layer of a back-propagation neural network,

(d) training said neural network to reproduce three values of tristimulus amplitudes for red, green and blue primary colors,

(e) employing an automated process comprising a continuous feedback loop, which includes the color mixing equipment, to allow corrections to the color recipe to be made until the color has been correctly matched.

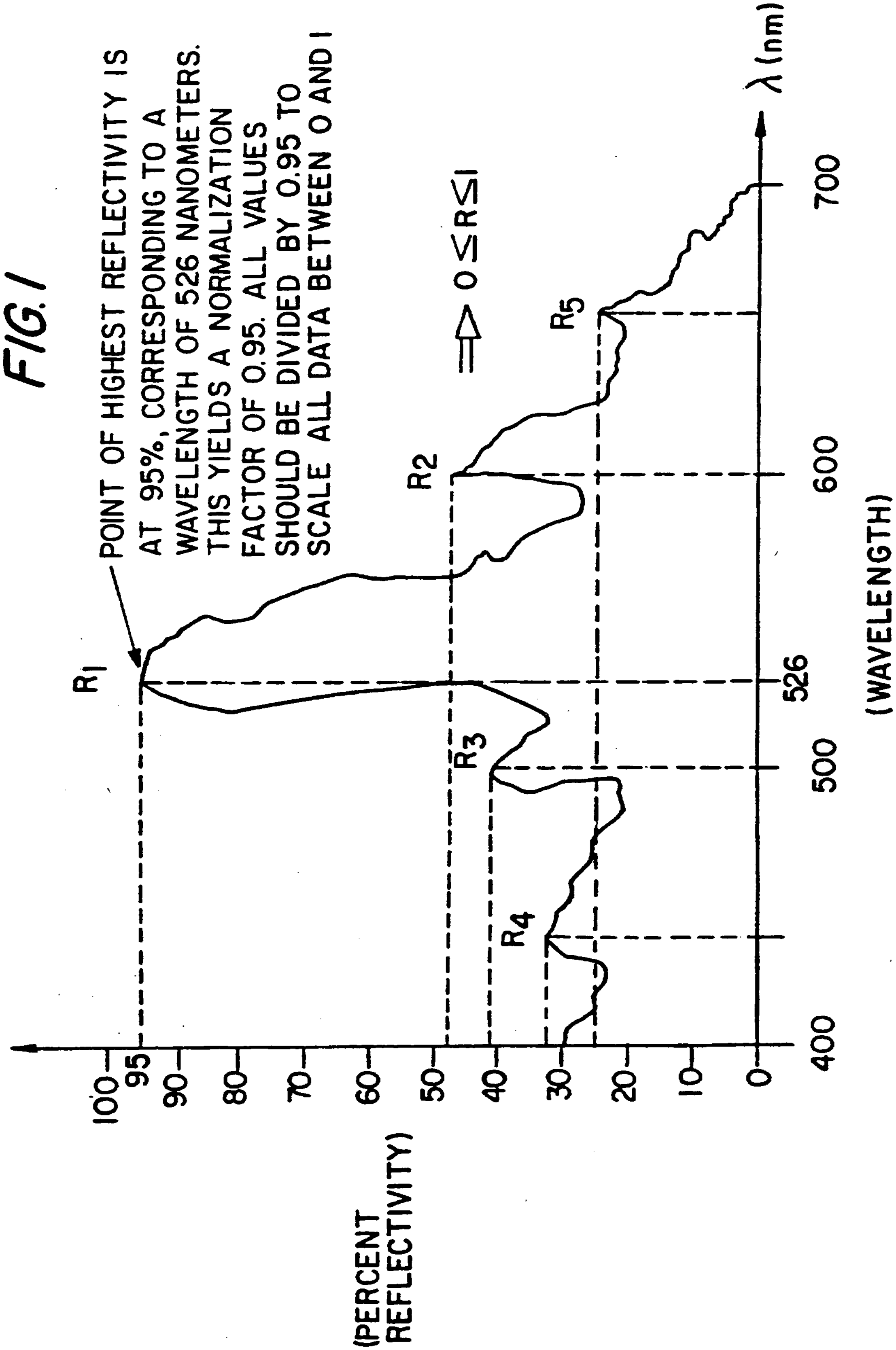
POINT OF HIGHEST REFLECTIVITY IS AT 95%, CORRESPONDING TO A WAVELENGTH OF 526 NANOMETERS. THIS YIELDS A NORMALIZATION FACTOR OF 0.95. ALL VALUES SHOULD BE DIVIDED BY 0.95 TO SCALE ALL DATA BETWEEN 0 AND 1
⇒ 0 ≤ R ≤ 1
R_1
R_2
R_3
R_4
R_5
100
95
90
80
70
60
50
40
30
20
10
0
(PERCENT REFLECTIVITY)
400
500
526
600
700
λ (nm)
(WAVELENGTH)

FIG. 1

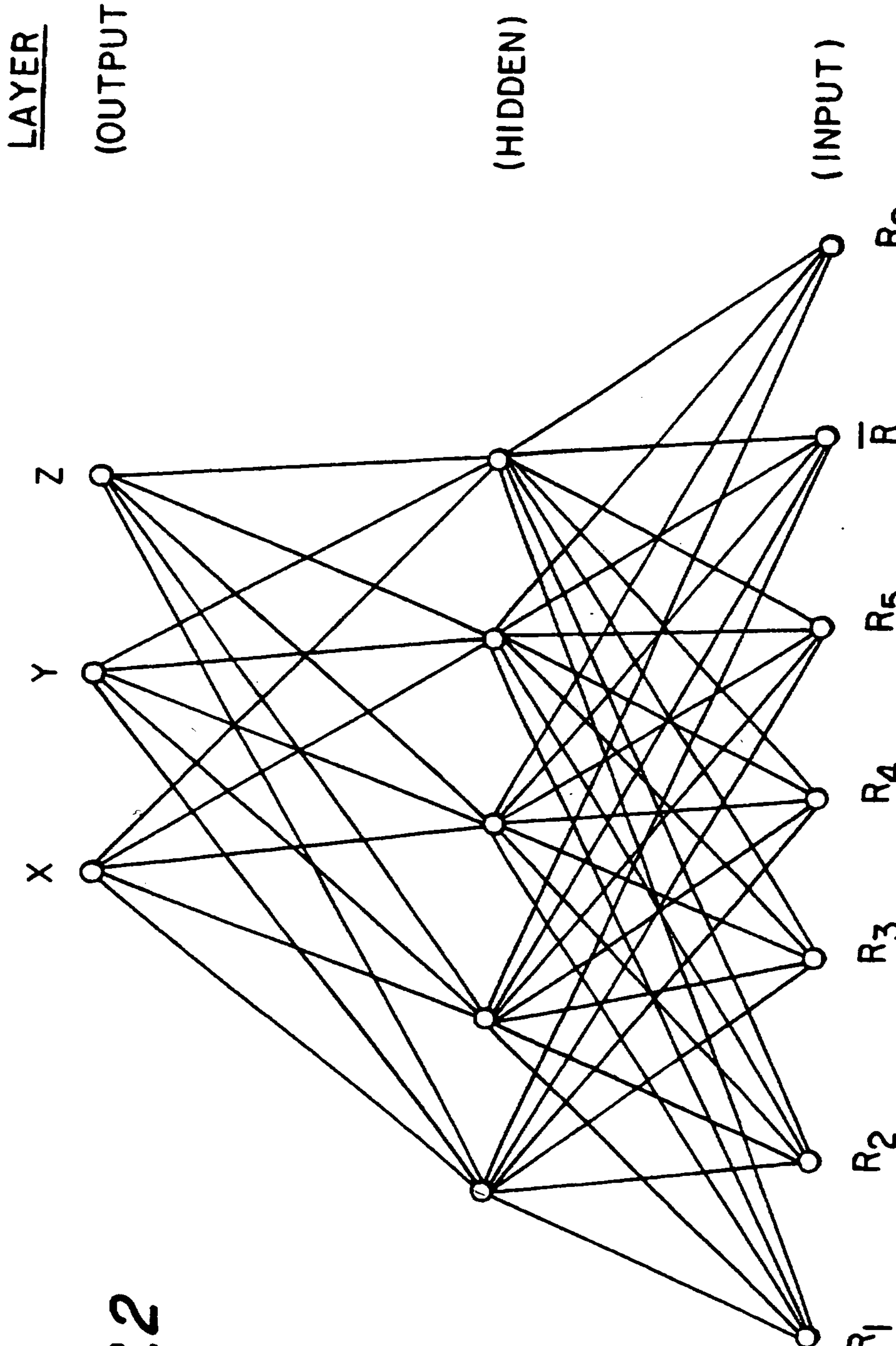

FIG.2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB97/01224

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01J 3/00, 3/46
US CL :364/526; 356/402; 358/80
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 364/526; 356/402; 358/80

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
search terms: color system, neural networks

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,200,816 A (ROSE) 06 April 1993 (06/04/93), col. 12, lines 14-16, col. 12, lines 59-63, col. 13, lines 20-24, and col.18, lines 4-7;	1-2
Y	US 5,012,431 A (STANZIOLA) 30 April 1991 (30/04/93), col. 4, lines 60-68.	1-2

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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